APPARATUS AND METHOD FOR VIRTUAL PROTOTYPING

OF BLOW MOLDED OBJECTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional patent application serial No. 60/441,419 filed January 21, 2003.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates generally to the design of blow molded objects and, in particular, to an apparatus and method for simulating the heating of a plastic preform.

2. Description of the Related Art:

Blow-molding operations typically involve encapsulating a heated plastic material such as a preform within the interior of a mold, applying a pressure to the interior of the preform so as to expand the preform against the mold cavity to form an article of manufacture. Issues concerning blow-molding operations involve the expansion of the material to the final desired shape. Expansion factors such as undesired thinning of certain areas of the article of manufacture

leads to further re-tooling of the mold in those critical

areas to reduce the effects of the unwanted expansion and

thinning. This trial and error process becomes costly as

new mold and/or performs need to be designed and created.

5 Furthermore, run times for producing prototypes of the

actual article are typically costly.

　　　　To reduce trial and error and to reduce the time of

design to production, computer aided design has been used

for designing of the mold. U.S. Patent No. 5,458,825

10 describes a method for producing a prototype of a blow

molded item by generating a data file of the geometry and

contours for the inner cavity of a mold utilizing a

computer aided design (CAD) apparatus. The data file is

used to create the mold from photosensitive resin

15 utilizing a stereolithographic apparatus. U.S. Patent

No. 6,116,888 describes utilizing CAD software to design

a hollow plastic container. The software model is used

to generate a software model of the corresponding mold.

The mold data file controls a cutting tool to machine the

20 mold.

　　　　However, these and other software design tools fail

to take into consideration a combination of factors such

as temperature affects of all heating and cooling sources

upon the entire preform, the stress/strain behavior of

25 the material throughout the molding process, and the

energy incident to the preform during the entire molding

process.

SUMMARY OF THE INVENTION

The present invention has the advantage of
simulating a heating of a plastic preform to determine
one or more cross sectional thermal profiles of a final
5 heated preform for modeling or virtually prototyping
plastic containers.

A method is provided for simulating a heating of a
plastic preform. A preform geometry is input into a
preform design program. Oven geometry and spatial
10 location of the preform throughout at least one oven is
provided. Heating information is provided and the
temperatures of the primary and secondary sources are
calculated. Energy equations are solved based upon the
preform geometry, the spatial location of the preform,
15 the temperature the cooling air, and the absorption
spectra of the preform material. At least one cross
sectional thermal profile of a final heated preform is
computed.

20   DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the
present invention, will become readily apparent to those
skilled in the art from the following detailed
description of a preferred embodiment when considered in
25 the light of the accompanying drawings in which:

Fig. 1 is a flow diagram of the method of virtual
prototyping in accordance with the present invention.

Fig. 2 is an illustration of secondary sources emitting radiation to the preform in accordance with the present invention.

Fig. 3 is an illustration of a preform transitioning
5 along an oven showing the preform at various locations within the oven incident to heating sources.

Fig. 4 is an illustration of a preform discretized into a plurality of blocks in accordance with the present invention.

10   Fig. 5 is an illustration of the discretized preform incident to the direct exposure and viewing angle of the heating sources in accordance with the present invention.

Fig. 6 is an illustration of the preform discretized at critical locations indicating transitional changes to
15 a shape of the preform in accordance with the present invention.

Fig. 7 is an illustration of the preform discretized into a plurality of intermediary sections according in accordance with the present invention.

20   Fig. 8 is a graph of a stress vs. axial stretch for a respective material in accordance with the present invention.

Fig. 9 is a graph of a stretch vs. blow pressure of a tube for the respective material in accordance with the
25 present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

There is shown in Fig. 1 a flow diagram of the method of virtual prototyping of plastic containers in

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accordance with the present invention. The method can be
implemented in software run on a computer. In a first
step 10, a container (e.g., bottle) design is created by
any known process thereby generating bottle geometry

5 data. This data is entered in digitized form into a
Preform Design Program 11 to generate digitized preform
geometry. Inputs to the program 11 are the bottle
geometry, the container and finish weight and the resin
stretching characteristic. Preform designs are created

10 so the designs may be stripped off of a core (i.e., error
checking for undercuts) and positions of transition
regions of the preform may be adjusted so that shoulder
regions of the preform coincides with that of the bottle,
if desired. A virtual prototyping module 12 receives the

15 digitized bottle geometry in a step 13 and the digitized
preform geometry in a step 14. A Preform Heating and
Blow Molding Program 15 simulates the heating and the
blowing of the preform into a prototype bottle. An Oven
Geometry step 16 defines the parameters of one or more

20 ovens which parameters are input into a Calculate View
and Shape Factors step 17 resulting in the spatial
location of the preform through the ovens. Oven geometry
parameters include lamp spacing, lamp length, lamp
position, reflector position, shield position, and oven

25 position. The spatial location is an input to a Solve
Energy Equations step 18 as is the digitized preform
geometry from the step 14.

     A Heating step 19 defines the parameters of the
heating sources which parameters are input into a

Calculate Temperature of Primary and Secondary Heating
Sources step **20**. Heating parameters include lamp
wattage, lamp power settings, overall power, reflection
coefficients, initial preform temperature, ceramic
5 coating, and initial preform temperature. A heating
preform module solves energy equations and computes at
least one cross sectional thermal profile of a final
heated preform. The temperatures from the step **20** are
input into the Solve Energy Equations step **18** as are
10 Cooling Air parameters (step **21**) and Vis/Infrared Spectra
of Material parameters (step **22**). The step **18** calculates
the radiation spectra to determine the energy incident
upon the preform which information is input to a Compute
Final Preform Temperature step **23**. To calculate the
15 radiation spectra in step **18**, the power input to the
lamps and their emission spectra is used for calculating
the temperature of the lamps. One of the inputs
comprises a filament enhancement factor which corrects
for any lamp element shielding. Secondary sources of
20 radiation like the temperatures of a backplate and
reflectors within the oven are calculated from energy
received and appropriate reflection coefficients of the
back plates and reflectors, respectively. Radiation
energy (E) from the heater at Temperature (T) and
25 emissivity (ξ) to a respective area (A_p) on the preform
between wavelengths λ and $\delta\lambda$ is calculated using Planck's
theory of quantum statistical thermodynamics given by the
equation:

$$Ej = \frac{\left(B_{j+1} - B_j\right)}{\left[e^{\left(\frac{14400}{T \cdot WL_j}\right)} - 1\right]} \bullet \frac{8950}{\left[\left(WL_j\right)^5\right]}$$

where T is a temperature measured in degrees Kelvin

$B_{j+1} - B_j = \delta\lambda$

5   WL is a wavelength measured in microns

The above equation is used determine the total
energy emitted for an entire range of wavelengths. The
values derived from the above equation when multiplied by
10 the emissivity of the lamps provides a real/gray body
radiation output that is used as the energy incident upon
the preform for absorption calculations.

The preform infrared spectra are input as absorption
values for the different wavelengths in an infrared
15 region of the electromagnetic spectrum. Also, the travel
of the preform through the ovens is discretized into
steps. A portion of the calculation involves determining
time spent at each respective step in the oven and the
exposure of the preform to each respective lamp a
20 respective step (shown in Fig. 3). This indicates that
regions closer to the lamp would have a greater amount of
energy incident upon it. The inputted preform geometry
is discretized (or digitized) into a plurality of small
rectangular blocks having a respective volume (shown in
25 Fig. 4). An amount of energy absorbed into each
discretized block is calculated and utilized for a

temperature calculation. Also, radiation transmitted
through a respective discretized block is used in
calculating the energy incident and absorbed in a next
adjacent discretized block. The radiation absorbed by
5 each respective discretized block is incident to the
direct exposure or viewing angle of each lamp as each
respective discretized block travels through the oven
(Fig. 5). Since each respective lamp will have a
respective viewing angle of a respective discretized
10 block at any given step throughout the oven, a view
factor for each discretized block at any given step in
the oven may be determined using the following formula:

$$V_f = (1/\pi) \int dA_p \int Cos\varphi Cos\theta \; dA_h/r^2$$

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where A_p = Area of Preform

A_h = Area of Heater

φ = Angle between normal to preform surface and
incremental area on heater

20   θ = Angle between normal to heater surface and
incremental area on preform

r = distance between the heater surface to the
preform surface (A_p to A_h)

25   The temperature of each discretized block of the
preform is calculated by solving a second order
differential heat transfer equation involving an energy
balance which accounts for radiation energy input thermal
conductivity of the material of the preform as a means

for transmitting the energy axially and radially.
Furthermore, other factors accounted for are any boundary
effects of cooling convective air current on an outer
surface of the preform as well as a relatively insulated
5 inner surface of the preform. The computation is
repetitiously performed until energy balance is achieved.

   In the preferred embodiment, the second order heat
transfer differential equation is represented by the
following formula:

$$k*\frac{d^2}{dr^2}T + \frac{k}{r}*\frac{d}{dr}T + \frac{Q}{A} = \rho*C*\frac{d}{d\tau}T \quad Units\ of\ Cal\ /\ cc*s$$

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where A= $2\pi r\Delta r$ (i.e., an area of incremental ring at
radius r and thickness Δr), Q represents an energy
generation term (i.e., energy per second per cm of
preform sidewall thickness), τ is representative of time,
15 ρ represents the density of the plastic, and k is the
thermal conductivity of the plastic.

The thermal conductivity constant (k) is represented by
CD and ρC is represented by HCD (Cal/cc*K). The heat
20 capacity (HCD) is a function of temperature. By
substituting these terms in the above equation, the
formula becomes:

$$CD*\frac{d^2}{dr^2}T + \frac{CD}{r}*\frac{d}{dr}T + \frac{Q}{A} = HCD(T)*\frac{d}{d\tau}T$$

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which is subject to the following boundary conditions
for the inside and outside surfaces of the preform which
are exposed to air. The boundary conditions are
represented by the following formulas:

$$-\left(\frac{d}{dx}T\right)\right] * k = h * (T - T\alpha),$$

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which leads to

$$\left(\frac{-k(T_i - T_{i-1})}{\Delta x}\right) = h * (T_i - T\alpha),$$

which leads to

$$T_i = \frac{\left(T_{i-1} + h * \frac{\Delta x}{k} * T\alpha\right)}{1 + h * \frac{\Delta x}{k}},$$

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where T_i is a wall temperature of the preform, h is a
heat transfer coefficient, and $T\alpha$ is the air
temperature. The heat transfer coefficients for inside
and outside preform surfaces are computed based on
15 empirically derived relationships of air velocity.

In the preferred embodiment, the calculated thermal
profile of each cross sectional area of the final heated
preform is input into a blow-molding module used to
determine the stress/strain behavior of the material and
20 simulate stretching of the heated preform. In other
preferred embodiments, the calculated thermal profiles

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may be used for other types of modeling such as finite element analysis.

The heated preform is then blown into a container in a Simulate Stretch Blow Molding step 24 based upon the
5 bottle geometry from the step 13, the preform temperature information from the step 23 and data from a Stress/Strain Behavior of Material step 25. The simulated blow molding proceeds to a Bottle Wall Thickness Profile step 26 where the thickness of each
10 section of the prototype bottle is determined. The thickness profile can be used in a Calculate Barrier Properties step 27. In simulating steps 24-27, the bottle geometry is input into the model by defining heights, diameters, and radii of curvature at critical
15 locations of the bottle. These areas of critical locations are defining points where transitional changes to a shape of the bottle are occurring (shown in Fig. 6). The intermediary sections are discretized into a plurality of sections (shown in Fig. 7) automatically by
20 the computer program. Alternatively, the intermediary sections may be entered into the computer program. To determine how strain hardening occurs and to what extent, the model considers the effect of stretching rate, extent of uni-axial and bi-axial stretching, preform temperature
25 and resin i.v. (i.e., intrinsic viscosity of resin) at each critical location or at each section. A relative stiffness factor is assigned to each section of the preform based on temperature and thickness. When applying a pressure or stress, the model determines which

respective section will stretch and to what extent each
respective section will stretch based upon a stress-
strain curve of a respective material at a given
temperature as it intersects an induced blowing
5 temperature. As a result, an axial and hoop (diameter)
orientation is computed for each respective section of
the preform as the preform is blown into a bottle and the
resultant thickness thereof. A graph of the stress-
stretch curves (i.e., for axial stretch) and stretch-blow
10 pressure curves (i.e., for hoop stretch) for a respective
material are shown in Fig. 8 and 9, respectively.

A design optimization module is used to optimize a
material distribution efficiency of the preform. A
Preform Design Optimization Routine 28 can be used to
15 optimize the preform geometry. The thickness profile
from the step 26 is input to a Calculate Material
Distribution Efficiency (MDE) step 29. The result of the
step 29 is input to a Revise Preform Geometry to Maximize
MDE step 30. The revised geometry is input into the
20 Solve Energy Equations step 18 and the blowing process is
simulated again. This optimization routine 28 can be
repeated until the best possible MDE is achieved.

In accordance with the provisions of the patent
statutes, the present invention has been described in
25 what is considered to represent its preferred embodiment.
However, it should be noted that the invention can be
practiced otherwise than as specifically illustrated and
described without departing from its spirit or scope.

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